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### **Redesigning Introductory Biology: A Proposal**

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### **Abstract**

With the increasing complexity and expansion of the biological sciences, there has been a corresponding increase in content in the first year introductory biology course sequence for majors. In general this has resulted in courses that introduce students to large amounts of material and leave little time for practicing investigative science or skill development. Based on our analysis of data compiled from 742 biology faculty at a variety of institutions across the United States, we verified that there is strong agreement on the content appropriate for introductory biology courses for majors. Therefore, we propose that faculty teaching these courses focus primarily on the topics identified in this study, and redesign their courses to incorporate active learning strategies that emphasize the investigative nature of biology and provide opportunities for skill development.

**Key words:** redesign, introductory biology, college biology, content topics, scientific skills, active learning

Critiques of undergraduate science education often focus on the introductory course sequence (Report of the AAMC-HMI Committee 2009, Timmerman *et al.* 2008, Committee on Undergraduate Biology Education 2003).

Although the breadth of content in introductory biology has increased over the past twenty years, the format for the course has not significantly changed (Wood 2009). Despite research indicating that courses focused on the development of critical thinking and analytical skills rather than memorization of content are more effective (Wood 2009, Timmerman *et al.* 2008, McDaniel *et al.* 2007), faculty involved in introductory biology courses for majors often resort to passive lectures in order to “cover” all of the material. This perceived pressure to emphasize breadth over depth often precludes the incorporation of active learning activities even though studies have demonstrated these activities lead to increased student engagement and learning (Chaplin 2009, Morse & Jutras 2008, McDaniel *et al.* 2007, Regassa & Morrison-Shetlar 2007, Cooper *et al.* 2006).

In the five recent initiatives for reforming the undergraduate biology curriculum reviewed by Labov *et al.* (2010), a common recommendation is to introduce less material but to cover topics in more depth. This same idea was the basis of a 2009 survey of members of the 2-Year and 4-Year College and University Sections of the National Association of Biology Teachers (NABT). The results of that survey of 310 instructors of major’s introductory biology with lab indicated that there was agreement on the concepts that students completing a year-long biology course sequence should know and understand (Gregory *et al.* 2011). Respondents were also surveyed on which critical thinking and laboratory skills students should develop in the course sequence. While that survey provided insight into the topics and skills that should be included in introductory college biology courses, it also raised a series of questions. Most important was that if there was widespread agreement to limit the topics covered in introductory biology courses, would this minimal topic set also be acceptable to instructors of more advanced biology courses. Additionally many of the survey respondents, while agreeing that there are approximately 25 weeks of instruction in the typical introductory biology course for majors, commented that some topics required a greater depth of understanding than others and requested some direction on the depth with which topics should be covered. Lastly, a frequent comment made by the survey respondents was the importance of laboratory exercises in the development of basic scientific skills and some respondents questioned if wet labs should also be a required component of the course.

To address these questions and concerns a new survey was developed and administered to a wider population of biology faculty at two and four year colleges and universities around the United States. Some of the questions asked in this survey and the lists of topics and skills were slightly modified to reflect what had been learned from the previous survey of NABT members. For example, the survey used in this study separated mitosis from the cell cycle, while these topics were combined in the topic list in the previous survey. Additionally, topics identified as essential by fewer than 20% of the respondents on the NABT survey were deleted from the topic list in the new survey. These included behavior, immunology, bioinformatics and social biology all of which had been identified by at least 60% of the NABT survey respondents as more suitable for advanced classes. The survey in the current study also made use of a different survey instrument (Opinio) in order to allow greater statistical analysis of subgroups of respondents. Distribution of the survey also differed between the previous survey and the one reported here. The NABT survey was limited to members of that organization who teach introductory college biology, while the survey used in this study was distributed to a larger number and more diverse group of college and university faculty. Of the 742 respondents who completed all parts of this new survey, 18.4% taught only introductory biology, 31.9% taught only advanced courses in the biological sciences, and 49.7% reported that they taught both introductory biology and advanced courses in biology.

There was a remarkable amount of agreement between both the NABT survey respondents and the wider population surveyed in this study as to the minimal set of topics that should be taught in introductory biology for majors. Respondents in this study were provided with a list of 36 commonly taught topics and asked to classify each as either “Essential” to be included in this course sequence, “Prior Knowledge” (a topic that should have been learned in high school and does not need revisiting in this course sequence), “Higher Level” (a topic that will be covered in a higher level course and does not require more than a brief introduction during this course sequence), or “Not Essential”. There was a limit of 25 topics that could be selected as Essential. The 25 topics most frequently identified as essential included evolution through prokaryotic diversity (Figure 1) and agreed very closely with the results obtained in the previous survey of NABT members.

This new survey was designed to allow respondents to specify the depth to which topics they identified as essential should be covered. The ten topics most often identified as essential, were also identified as the top ten topics when sorted by the amount of depth to which the topic should be covered (Figure 2). This correlation between the frequency with which a topic was identified as essential and the recommended depth of coverage remained consistent for the top 25 essential topics with two exceptions. While knowledge of chemical structures was ranked relatively high (#11) in terms of requiring in-depth coverage (Figure 2), it was also was the topic with the highest ranking as Prior Knowledge (Figure 1). Respondent comments helped explain this apparent discrepancy by stating that while students should enter the course understanding this material that they often lack this prior knowledge. A similar but less dramatic pattern was seen in the responses for mitosis. This topic also received a relatively high ranking as Prior Knowledge but ranked fourth in regards to the amount of depth in which it should be covered.

The data from this current survey indicate that there is a consensus that the basic cellular and molecular concepts that apply to organisms in all domains should be covered in-depth or at least at a basic level. Topics that fell into the top 25 topics identified as essential and were also identified by at least 30% of the 742 respondents as only requiring exposure, tended to be more specific in nature such as animal, plant, and prokaryotic diversity. Other topics that respondents frequently identified as requiring only exposure such as anatomy, development, and biotechnology were also identified as more suitable for advanced courses. It should be noted that there were no significant differences in the ranking of topics in this study by those who teach only advanced biology classes and those who teach introductory biology, indicating that there was wide agreement on the essential topics and the recommended depth of coverage among all faculty surveyed.

We believe that the combined data from Figures 1 and 2 indicate that there are 23 topics that instructors of introductory and advanced biology courses agree should constitute the minimal set of material for introductory biology courses for majors at all higher education institutions. Specifically, introductory biology courses for majors should cover the following topics in-depth: evolution, cell structure, DNA structure and replication, mitosis, meiosis, Mendelian genetics, cell cycle, protein synthesis, membranes and transport, respiration, photosynthesis and enzymes. Additionally students in these introductory course sequences should also have at least a basic understanding of the following topics: chemical structures, bioenergetics, speciation, ecosystems and conservation,

genetic recombination and mutations, populations and communities, sexual reproduction of both animals and plants, diversity of animals and plants, and cell communication. While instructors would be free to include other topics based on their personal interests or that of their students, establishing this minimal set of topics would provide a guideline for instructors wishing to redesign their introductory biology courses for majors to focus on fewer topics in more depth. The immediate benefit of this would be to allow more time for the utilization of teaching methodologies that engage students, enable them to develop a deeper understanding of concepts, and improve their ability to apply this knowledge to real-world problems. The designation of this set of required topics would also inform instructors of advanced courses precisely what knowledge can be assumed for students entering their courses, and insure that students who complete their introductory courses at one institution are also prepared for advanced work at other institutions.

While this survey also investigated the importance of critical thinking and scientific skills, there were no significant differences between the skills selected as essential to introductory biology courses with lab for majors between the respondents to this survey and the previous NABT survey. We have no additional recommendations in regards to skills development than what has already been published (Gregory, et al. 2011). However this study did investigate the importance of inclusion of a laboratory component in introductory courses for biology majors. The reason for the inclusion of this aspect of the course to the survey was twofold. First, a significant number of the optional open-ended responses on the NABT survey concerned the necessity of a laboratory component, and second, when presenting the results of the original survey at several national conferences, the majority of attendees' questions and comments concerned what they saw as increasing pressure to utilize virtual labs in large enrollment introductory biology courses. Therefore we polled survey respondents on the necessity of wet labs in introductory biology courses. Over 96% of respondents felt that laboratory exercises requiring student experimentation occurring at a lab bench and utilizing scientific equipment and materials are an essential component of the course.

Regardless of the type of institution where they teach, the majority of all respondents to the current survey indicated that wet labs should comprise over 50% of the labs; 37.7% believe wet labs should constitute 51-75% of the lab component while 42.9% felt 76-100% of the labs should require student experimentation at a lab bench (Figure 3). While there was no significant difference in responses among the three groups, faculty who teach at 4-year

institutions with both graduate and undergraduate programs were slightly less committed to the importance of wet labs. Interestingly, 100% of the 71 respondents who teach both introductory biology and microbiology felt that wet labs were an essential part of introductory biology, with the majority of them (55%) stating that at least 76-100% of the labs should require student experimentation with scientific equipment and materials.

## **Conclusions**

The results of this study represent the thoughts of the largest number of biology instructors surveyed to date. Based on these results and those obtained in a previous survey (Gregory et al. 2011) we believe that there is a national consensus on which biological topics and scientific skills are essential to the introductory course sequence for biology majors. Instructors of introductory biology should redesign their courses to focus on these essential topics and skills identified by their colleagues. We should not feel pressured to cover all the material presented in textbooks, and instead should design our courses to provide students with the information and skills that they require to succeed in today's world. It is only through providing the opportunity to apply and utilize their knowledge that we can prepare students with the information and skills needed to be successful in advanced courses. We hope that the conclusions provided here will lead to the endorsement of a standardized minimum curriculum for introductory courses for biology majors by the scientific community and the adoption by faculty at two and four year colleges and universities.

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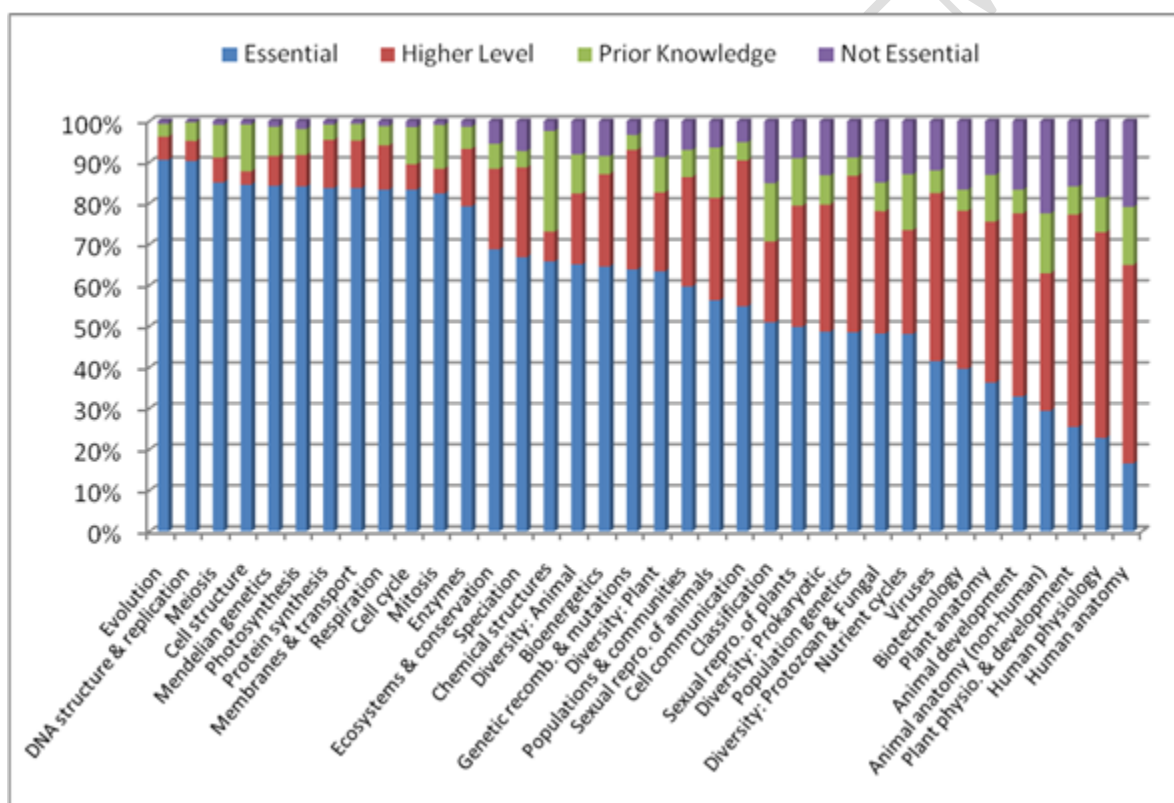
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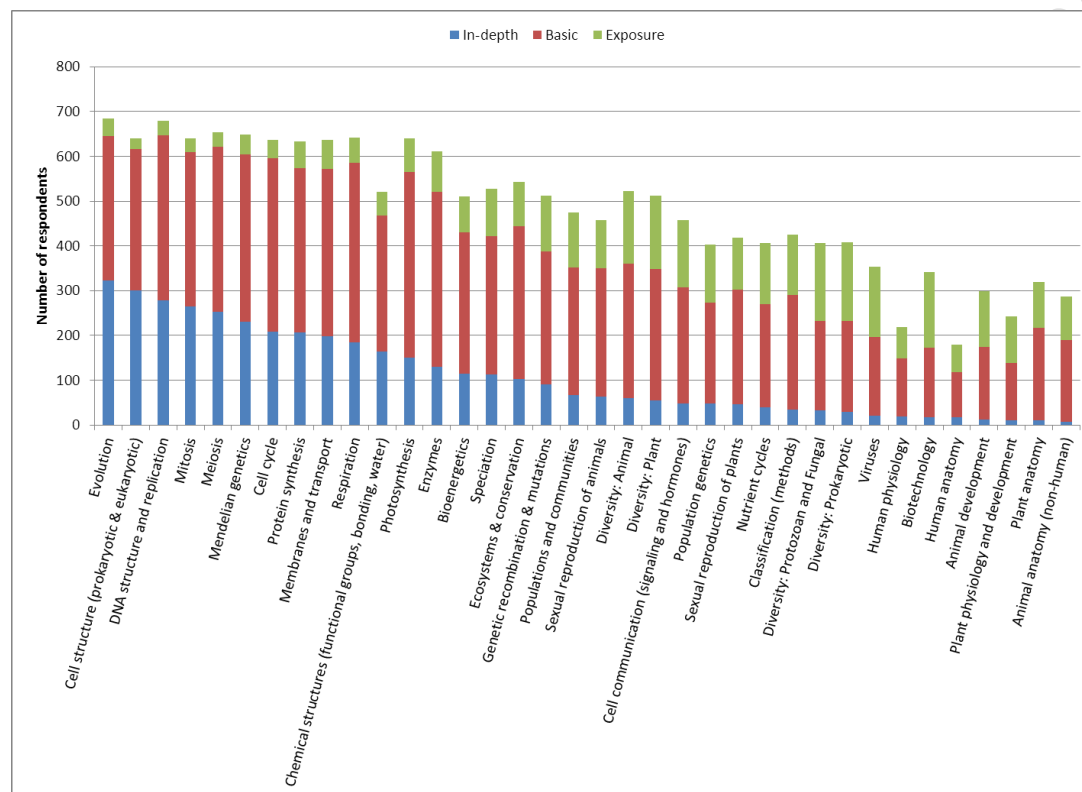
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**Figure 1:** Classification of topics by ranking as essential for year-long introductory biology sequence (n=742).

Twenty-five topics were selected as *Essential* to be covered in a general biology course sequence for biology majors, at any depth of coverage; the remaining topics were classified as *Prior Knowledge* (a topic that should have been learned in high school and does not need revisiting in this course sequence), *Higher Level* (a topic that will be covered in a higher level course and does not require more than a brief introduction during this course sequence), or *Not Essential* for biology majors in this course sequence. Topics are sorted by their ranking as *Essential*. All 36 survey topics are presented.



**Figure 2:** Classification of topics by depth of coverage for year-long introductory biology sequence (n=742). For topics identified as essential, respondents were required to specify if the material should be covered to provide in-depth understanding, basic understanding or if the students should only be exposed to the topic. Topics are sorted by their ranking as requiring in-depth understanding. All 36 survey topics are presented.



**Figure 3:** Percentage of laboratories that should require student experimentation at a lab bench utilizing scientific equipment and materials. Responses were categorized as: All respondents (blue, n=742), 2-year institution (red, n=177), 4-year institution with focus primarily on undergraduates (green, n=314) or 4-year institution with undergraduate and graduate programs (purple, n= 235).

